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APPRAISAL OF ISRAEL'S WATER RESOURCES AND THEIR ALLOCATION

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by

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I N T R O D U C T I O N

Since the territory of Israel is a strip of land lying between the sea and the desert, its climate is far from uniform. With rainfall occuring only in the winter season (between November and March), the productivity of unirrigated land is limited. The lower temperatures characteristic of the rainy season confine dry farming in most areas to grain of relatively low value. Furthermore, the year-to-year variability of rainfall results in uncertainty as to crop yields, particularly in the south, where total crop failures are frequent.

With irrigation, on the other hand, the range of production is considerably widened. A great variety of high-value crops (especially citrus) can be grown if a reliable water supply is provided. Hence, the high demand for irrigation water, which was supplied in 1961 to the amount of 870 MCM .

The country's rapidly growing industrial production also causes steadily increasing demands for additional water. In 1954/55 approximately 160 MCM were supplied for urban and industrial uses; more than 275 MCM were supplied during 1961; a considerable part of this increment is due to industrial growth. In the next decade a growth in industrial production exceeding 10% is anticipated annually thus the rise in the industrial demand for water over the next eight years is estimated at 80 - 100 MCM.

Israel has now reached a stage where the demands for water in agriculture and in industry are already competing. The eight-year plan (1962 - 1970) for the development of water resources in Israel, tries to resolve this conflict by using advanced methods of appraisal of the potential water resources, and by determining criteria for the allocation of water to different uses.

AVAILABLE WATER RESOURCES

Unfortunately, there is a considerable distance between the location of the sources of supply and the centres of highly concentrated demand - the large blocks of irrigated lands and the main industrial areas.

MCM = million cubic metres

Almost two-thirds of the arable land of Israel is located south of Tel Aviv, the approximate half-way point on Israel's 400km. border-to-border length. In this southern zone, only 15% of the potential water resources are found. Hence, water surpluses over and above local demand occur in the north, whilst most of the remaining irrigable yet undeveloped lands and areas of prospective industrial development lie in the south. This difficulty had to be overcome in the past by costly conveyance systems over long distances. Undeveloped water resources will also have to be conveyed by similar systems, the largest being the Jordan project with its 108" dia. cross-country pipeline.

The topographical situation is likewise unfavourable: almost 70% of the country's water resources occur at an elevation only slightly above sea level, another part in depressions down to 200 m. below sea level, whilst the elevation of most irrigable lands varies between 70 and 200 m. above sea level. To overcome this unfavourable topographical distribution, water has to be pumped necessitating an average energy consumption of approximately 800 watt-hours per cu.m. of water supplied.

The annual amount of 1,500 MCM of fresh water will be developed by 1970. This figure represents the "permissible" annual yield of the proven freshwater resources, considered safe for continuous utilization. They are roughly composed of:

Rivers	33%
Groundwater	54%
Reclaimed sewage	8%
Intercepted storm run-off	5%

The estimates are based on very advanced appraisal methods, and their accuracy is probably higher than the one usually accepted in many countries; still some inherent inaccuracy remains.

METHODS OF APPRAISAL

Perpetually short of water, Israel devotes the energies of her specialists to exploring hitherto unused water resources, and to intensify the use of partly developed ones. A prerequisite to intensive development is the application of advanced appraisal methods.

The appraisal of river flow has been achieved by conventional methods. Since the rivers are few in number and their flow is small, conventional methods of gauging and of statistical analysis are being utilized as elsewhere.

A more difficult and weighty problem however was the appraisal of groundwater. It represents not only the most important water resource of Israel, but also poses the most complex problems.

Appraisal of Groundwater Resources

Groundwater in Israel occurs mainly in two water-bearing formations: the shallow sand and sandstone aquifer situated along and discharging directly into the Mediterranean, and the deep limestone aquifer draining the outcrops of the Galilean mountains, the Carmel range and the Judean hills. The later formation feeds at least three of the perennial rivers discharging into the Mediterranean.

The Shallow Aquifer

The shallow coastal aquifer is now almost fully utilized by a large number of boreholes. Intensive exploitation inevitably results in a certain encroachment of sea water which may endanger the whole aquifer.

Hydrological investigations in this coastal aquifer are based on a network of observation wells. The network, arranged in 2 km. x 2 km. squares, includes more than 300 observation wells reaching down considerably below the groundwater table. 40 - 50 wells were equipped with automatic level recorders. A further 40 deep boreholes, penetrate to the lower impervious layers. This last group was constructed in order to identify the underlying strata. They enable a close observation of the movement of the saltwater - freshwater interface. More specifically the network was designed for the following purposes:

(a) Recording of groundwater levels and studying their fluctuations;

(b) Geological information with special emphasis on the location of impervious strata (aquicludes);

(c) Providing data for calculating the main constants of the aquifer, i.e. its transmissivity and storativity in each particular area;

(d) Introducing groundwater tracers (dyes and radioactive isotopes) and observing or sampling their intensity;

(e) Determining the location of the salt -- freshwater interface along the coast and determination of changes in the width of its dispersion zone;

(f) Elucidation of the subsurface geology of the aquifer and of the interconnections existing between its different layers;

(g) Determination of the total volume of the aquifer.

The observation well network has yielded a vast amount of geological and hydrological information. A detailed geo-hydrological map of

the coastal zone has been drawn and water balances calculated for individual areas.

Equations for the water balances of individual areas were based mainly on data obtained from water-level contour maps compiled from levels recorded in the observation wells. Special care has been given to the proper distinction between the upper phreatic water table and the groundwater potentials in the lower water-bearing formations, in order to ensure that the data used in the plotting of contours refer to the same aquifers.

Additional data for these balances was obtained by pumping and recharge tests. The tests were conducted and interpreted by conventional methods. However, owing to the high density of the pumping wells in the coastal aquifer, disturbance of observations by pumping from neighbouring wells could not always be eliminated and therefore these tests were only of limited usefulness.

All these methods supplement each other and result in a detailed physical model of the aquifer. Behaviour of the system under various schemes of operation was then studied by conventional mathematical methods and a Hele-Shaw type analog model simulating the geological configuration and the hydrological constants of the aquifer. These constants, including storativity, transmissivity, natural replenishment (either vertically by infiltrating rain or laterally by inflow from other formations), hydrological boundaries of the aquifer, and the general groundwater regimen, are all needed in estimating the permissible exploitation and in elaborating an exploitation scheme for the area.

Such an exploitation scheme has to be based on a predetermined position of the saltwater - freshwater interface in a "steady state" condition to be reached at some future date. The movements of the saltwater - freshwater interface were also simulated on a proper time scale, on the Hele-Shaw model. In order to maintain the chosen position of the interface, the groundwater potential at a certain distance inland of the coast has to be kept at a predetermined level.

However, until the final steady-state groundwater levels are reached, permissible withdrawals can be increased, by taking full advantage of the so called "one time reserve". This one-time reserve is composed of

(a) The volume of water contained in the formation between the initial and final position of the water table; and

(b) The freshwater displaced by the contemplated inland movement of the saltwater-freshwater interface.

The basic mechanism involved is clear. Until withdrawals from the formation started, the whole natural replenishment was being

discharged into the Mediterranean. After intensive pumping from the aquifer, however, an intermediate state was created, with the levels of groundwater dropping and its seaward flow reduced. In the proposed final "steady state" pumping rates will not exceed the permissible withdrawals, and an appropriate seaward flow of groundwater will still be maintained to keep the intruding sea water within the predetermined distance. The permissible sea water intrusion can be defined somewhat arbitrarily.

The permissible extent of inland movement of seawater defines the unavoidable loss to the sea: the greater the inland movement, the smaller the loss, but the higher the risk involved. Such calculated risks can be incurred only by having available for the operation the fullest and most detailed data on the geology and hydrology of the coastal aquifer.

The Deep Aquifer

The second main source of supply, which accounts for the country's remaining groundwater and for a considerable part of the surface flows appearing as springs, is the Turonian-Cenomanian aquifer of the country's hilly region. This aquifer is of high complexity.

The water is known to be of excellent quality. In a few cases however it turns saline "all at once", as for example in the case of the Tanninim river near Caesarea or the Naaman river near Haifa.

Even freshwater springs are not an unmitigated blessing in a semi-arid country like Israel. The peaks of spring-yield occur in winter when demand is at its ebb. Seasonal storage in artificial surface reservoirs is costly and wasteful as it entails large losses by evaporation. It is therefore advantageous to decrease spring flow by artificial abstraction of groundwater through boreholes so that the combined hydrograph of spring flow plus pumpage from boreholes shows a peak in summer and satisfies demands.

Plans for the control and diversion of spring flow by pumping from wells necessitated detailed quantitative investigations. In this context methods of analysing and predicting the spring hydrograph were developed. The decay characteristics of a spring (i.e. characteristics of the hydrograph during the dry season) are a function of the geometry of the groundwater reservoir, its storativity and the driving head. Only the driving head represents a variable parameter. Analysis of the spring hydrograph enables calculation of the "state of fullness" of the groundwater reservoir corresponding to a given instantaneous yield of the spring. From here, if the scheme of artificial abstraction is specified, future behaviour of the system can be predicted.

The Tanninim river represented the most crucial case. It has a comparatively large discharge (for a semi-arid country), and its favourable geographical situation coupled with the stability of its

flow would have made it an important source of water, but for its high salinity. The subterranean flow channels which feed this river were studied with the aim of finding the causes of the river's high salinity and of formulating plans for interception of the available flow by wells before the water becomes saline. As a result, an exploitation plan was drawn up and a considerable part of the underground flow is intercepted while still fresh.

In the case of the Naaman river, almost all the groundwater which previously issued from saline springs is now diverted through boreholes as freshwater. The observed water levels and residual spring flow tally very closely with theoretical predictions. It was even found possible to control the rate of reduction of spring flow during different seasons.

ADVANCED PLANNING OF THE USE OF RESOURCES

Failure to foresee results of uncontrolled development of groundwater resources, may do irreperable damage.

Since Israel is now nearing very closely the permissible limits for exploitation, it became imperative to develop adequate tools for much more detailed appraisal and control than available hitherto, when theories and measuring techniques for predicting the rate of water movement were available for only a few sets of conditions, and in a rather generalised form. Among the results of efforts towards an intensified but fully controlled utilization of the available water resources, mention must be made of two recent developments in Israel, namely that of underground storage of surface waters and that of the coastal groundwater collector.

Underground Storage of Surface Waters

Geological and hydrological criteria have been developed for evaluating the suitability of aquifers for artificial recharge of surface waters and for temporary storage for subsequent use. Special study was made on the effect of recharge operations on groundwater quality, especially when the chemical composition (mineral contents) of the recharged water is different to that of the aquifer. An example of the recharge of water with higher mineral concentration into a relatively fresh aquifer will be the recharge of Lake Tiberias water into both the coastal and Cretaceous aquifers. Very considerable amounts of water will be recharged into and withdrawn from these two aquifers during a few months every year for the purpose of seasonal and long-year regulation of the Jordan water supply project.

Coastal Groundwater Collector

The basic idea of the coastal collector to be laid parallel to the Mediterranean coast, is to reduce to the minimum the outflow of groundwater to the sea, necessary to protect the aquifer. Pilot plants of various types (shallow wells, drains) have been constructed to verify the extent to which, under prevailing geological conditions, the seaward seepage of groundwater may be reduced below the amounts hitherto accepted as necessary.

Laboratory model tests and preliminary calculations indicate the possibility of intercepting a considerable portion of this outflow without endangering the aquifer. The amount of water intercepted in this way is estimated to increase the hitherto permissible maximum for exploitation by about 8%.

Evaporation Control

Planned management of natural vegetation and regular control of groundwater levels in areas where a high water table may lead to excessive evaporation through capillary action, offers possibilities of saving more water and thus increasing water yields. An example of practices holding such promise are black-radiation measurements (from helicopter) of various types of vegetative cover, to determine the feasibility of saving water by reducing the density of brush cover along water courses, by regulating the water courses themselves, and by planting chosen types of vegetation that may forestall the development of water consuming plants.

Waste Prevention

Last but not least, the available supplies may be increased by the reduction of waste. Extensive research in this field has now been initiated in parallel with the appraisal of naturally available resources. Measures applied for decreasing the waste of water in irrigated areas, concentrate mainly on:-

(a) Minimising losses, in storage and transport, due to seepage and evaporation and consumption by non-beneficial plants. A complex system of open water channels in the Hula irrigated region in northern Israel is being replaced by closed pipe systems (more than 80% of all distribution systems in Israel are closed pipe systems);

(b) Proper timing of irrigation, and its precise adaptation to the physiological requirements of the plants;

(c) Thorough analysis of climatic and soil characteristics in each region, to determine the optimum conditions for crop development;

(d) Analyses of comparative yields of crops under various

applications of water, mainly with the aim of reducing the amount of water applied per unit of area, and in order to obtain maximum crops per unit volume of applied water.

The measures adopted to reduce excessive use of water in municipal and urban areas are based mainly on universal metering, coupled with progressively increasing rates. The rates structure does not represent the real cost of production of marginal quantities of water used; it is a deterrent measure aimed in the last count at equalizing the rate for such marginal uses with the cost of the only unrestricted supply potentially available, i.e. the demineralization of sea water.

With further developments and the initiation of sewage reclamation on a large scale, it will become clear whether this measure of universal metering and rates are justified. Doubts that may arise in this connection stem from the very high percentage of the municipal supply reappearing in the sewers - since the returning sewage constitutes 87%, only 13% of the water supplied to the towns represents a real consumptive use, and only a part of this use can be saved by the adopted measures.

CRITERIA FOR ALLOCATION OF WATER RESOURCES TO COMPETING USES

Taking into account the very high proportion of the available resources already under regular utilization, it is justified to predict ultimate limitations to the development of agriculture. The supply of water for irrigation has risen from 260 MCM in 1949 to 870 MCM in 1961. The volume of agricultural output increased during that period in terms of constant (1961) prices from IL.220 million to IL.1,070 million in 1961.

The presently available water resources will never suffice to irrigate all undeveloped irrigable land. Extensive investigations have been initiated to determine the marginal productivity of water in various regions and under different crop patterns. The results will then be compared to those for alternative uses in industry and will guide the allocation of the marginally available scarce supplies.

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